

Evaluation of the Arctic Surface Radiation Budget in CMIP5 models

GOAL →

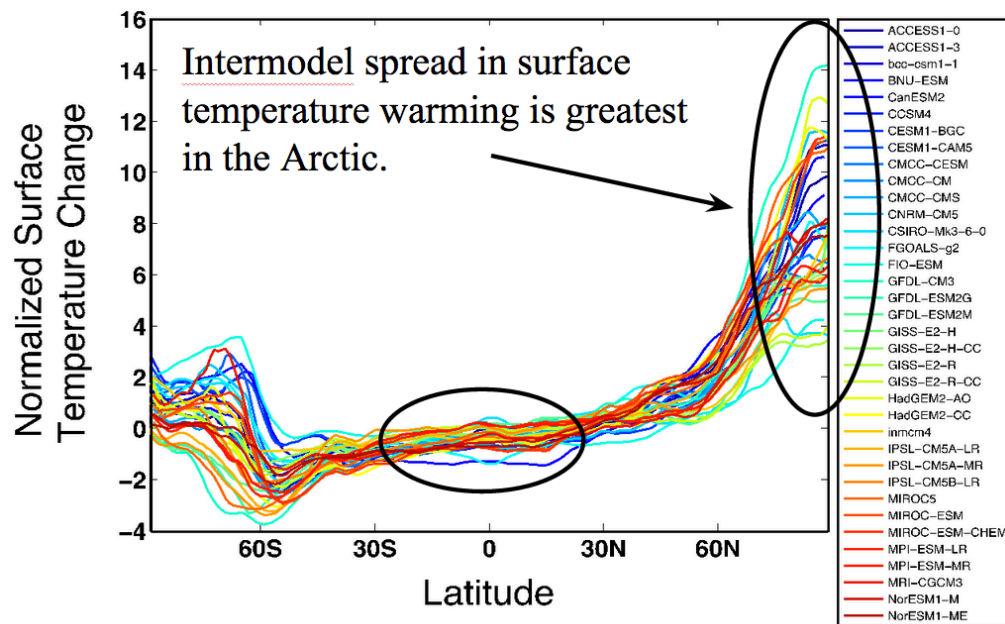
Determine biases in the representation of the Arctic surface radiation budget annual cycle and discover the physical processes that explain the significant spread in projected Arctic warming.

Robyn C. Boeke and Patrick C. Taylor
Science Systems and Applications, Inc.
robyn.c.boeke@nasa.gov

image credit: www.awi.de

The Arctic climate is rapidly changing

Arctic surface temperature is increasing at a rate outpacing the rest of the globe, and the projected Arctic temperature response to increasing CO₂ is larger than that for the tropics.



Credit: Noel Baker

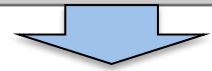
Studying the Arctic climate presents unique challenges.

- The largest intermodel spread in projected surface temperature warming is found in the Arctic.
- Satellite observations are difficult, lack of in-situ measurements

Understanding and reducing intermodel spread in the simulation of the surface energy budget can improve future projections.

Radiative and non-radiative feedback processes lead to polar warming amplification

Surface Albedo Feedback



The surface warms

Additional solar radiation is absorbed

Less reflective land and ocean surface are exposed

Atmosphere/ dynamical transport feedbacks

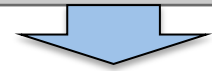


Poleward atmospheric heat transport increases (Pithan and Mauritsen 2014)

Sea ice retreats and thins

Thinner and less extensive sea ice amplifies the surface albedo feedback

Cloud feedbacks



Arctic cloud forcing is two-fold

POSITIVE FEEDBACK

More clouds increase downward longwave radiation at the surface

NEGATIVE FEEDBACK

Clouds increase albedo and reduce downward shortwave radiation

In summer, these effects compete. In winter (in the absence of solar radiation), the longwave cloud radiative effect dominates.

Use the concept of cloud radiative forcing to evaluate the influence of clouds on shortwave and longwave fluxes at the surface.

$$\text{CRE} = (\text{SW}\downarrow - \text{SW}\downarrow_{\text{clr-sky}}) \cdot (1 - \alpha) + (\text{LW}\downarrow - \text{LW}\downarrow_{\text{clr-sky}})$$



“Cloud Radiative Effect”

where

- $\text{SW}\downarrow$, $\text{LW}\downarrow$ are all-sky fluxes
- $\text{SW}\downarrow_{\text{clr-sky}}$, $\text{LW}\downarrow_{\text{clr-sky}}$ are clear-sky fluxes
- α is the albedo calculated using clr-sky sw fluxes, $\text{SW}\uparrow_{\text{clr-sky}}/\text{SW}\downarrow_{\text{clr-sky}}$

Terms in the equation represent cloud influence on solar and infrared radiation

$$(\text{SW}\downarrow - \text{SW}\downarrow_{\text{clr-sky}}) \cdot (1 - \alpha)$$



Shortwave cloud radiative forcing (SW CRE)

Usually negative because downwelling solar flux decreases with the presence of clouds

Magnitude of SW CRE is smaller over a white surface than over ocean

$$(\text{LW}\downarrow - \text{LW}\downarrow_{\text{clr-sky}})$$

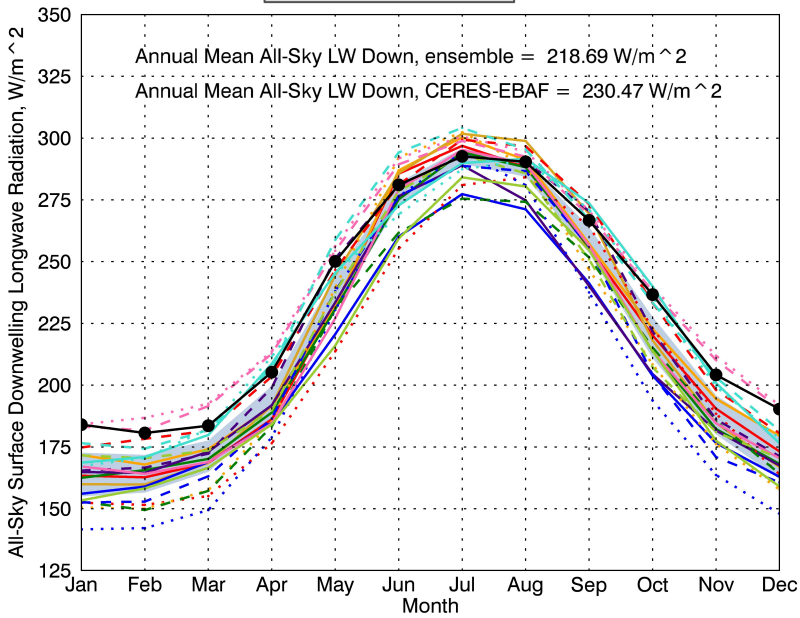


Longwave cloud radiative forcing (LW CRE)

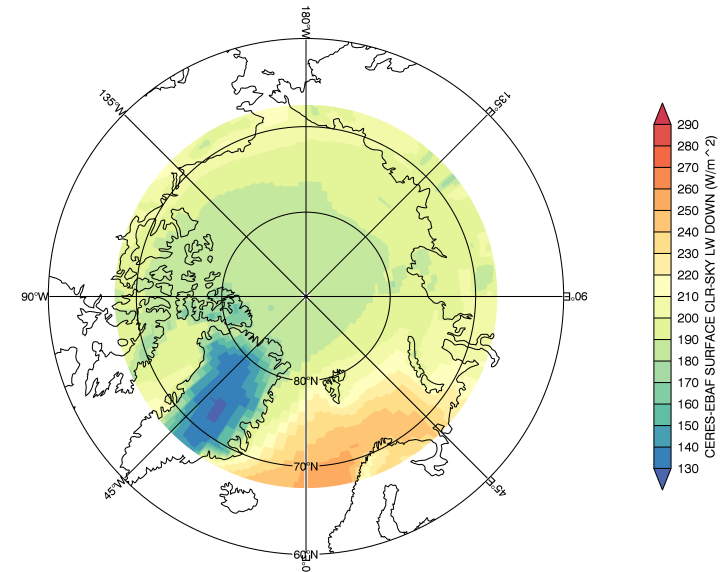
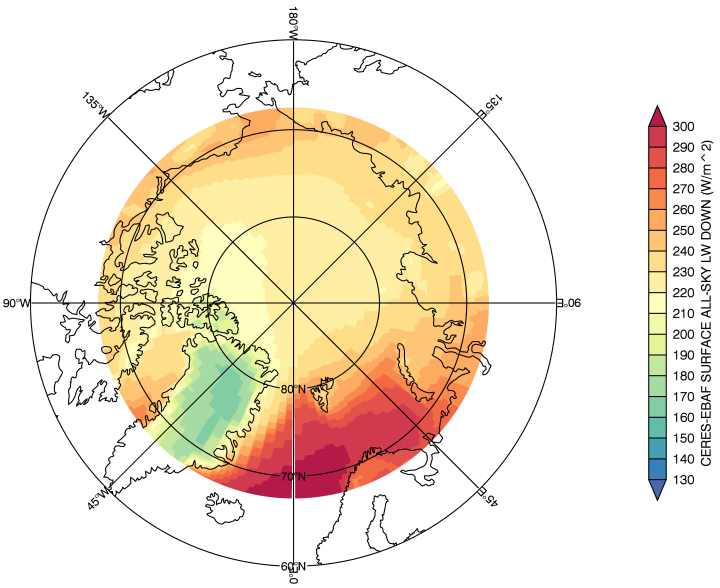
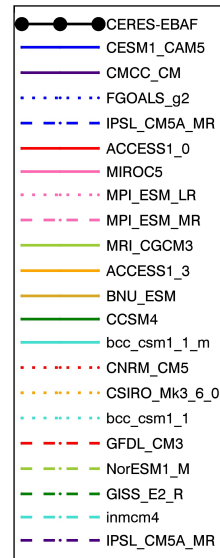
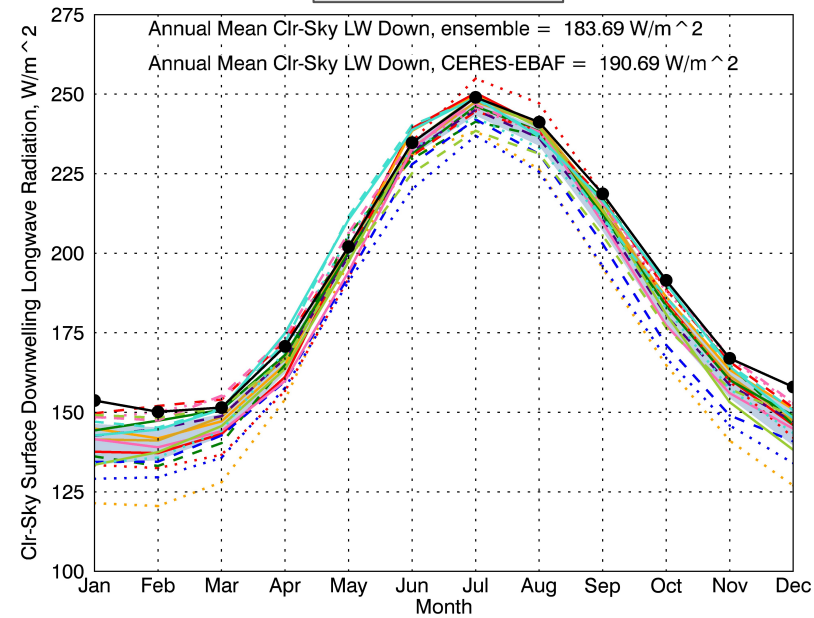
Usually positive because downwelling longwave radiation increases with the presence of clouds

Longwave Surface Fluxes

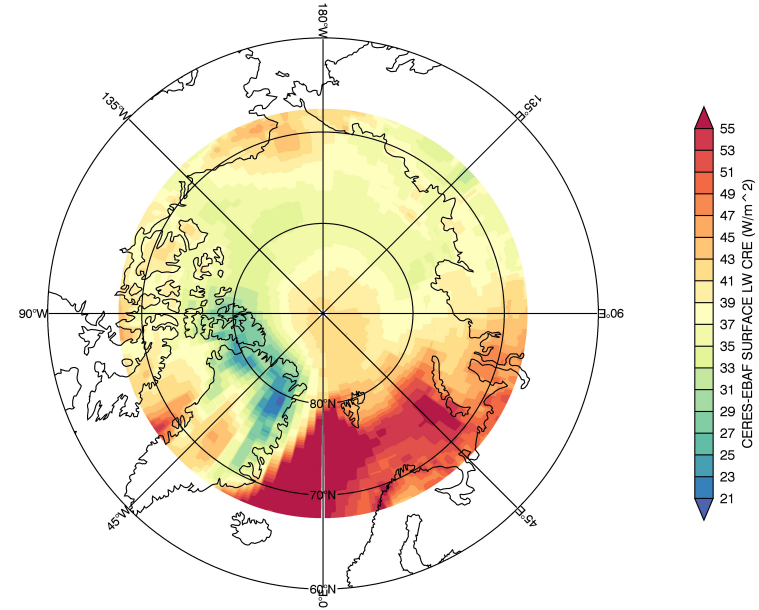
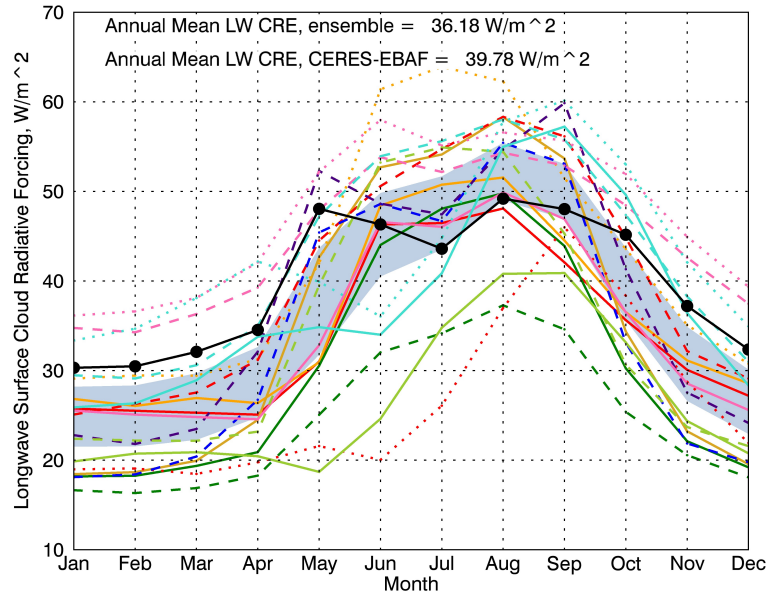
All-Sky



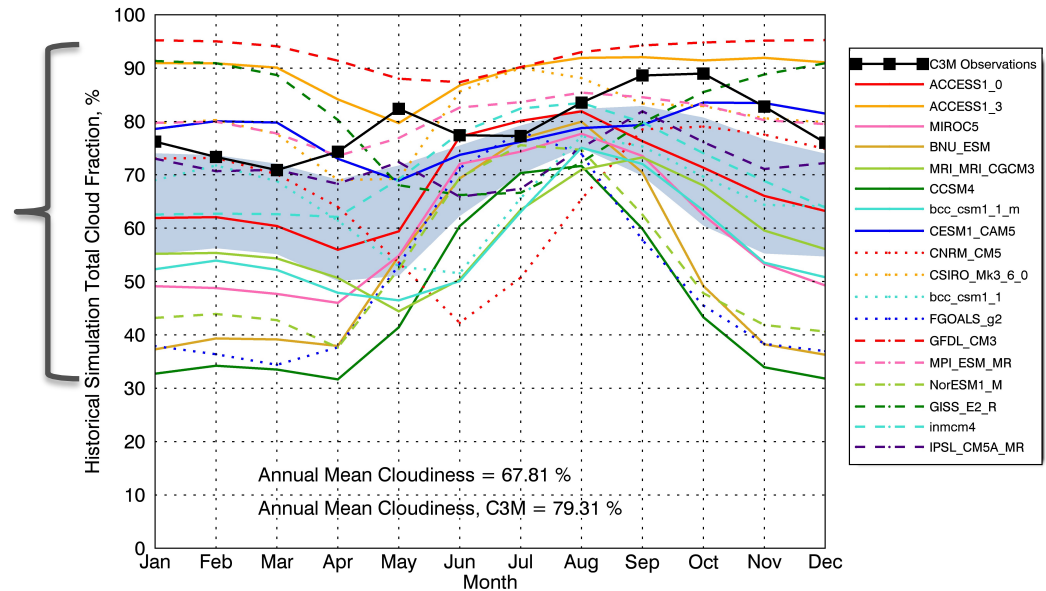
Clr-Sky



Longwave Cloud Radiative Effect



The large discrepancy in wintertime cloudiness is due to the representation of low clouds (Karlsson and Svensson 2011)

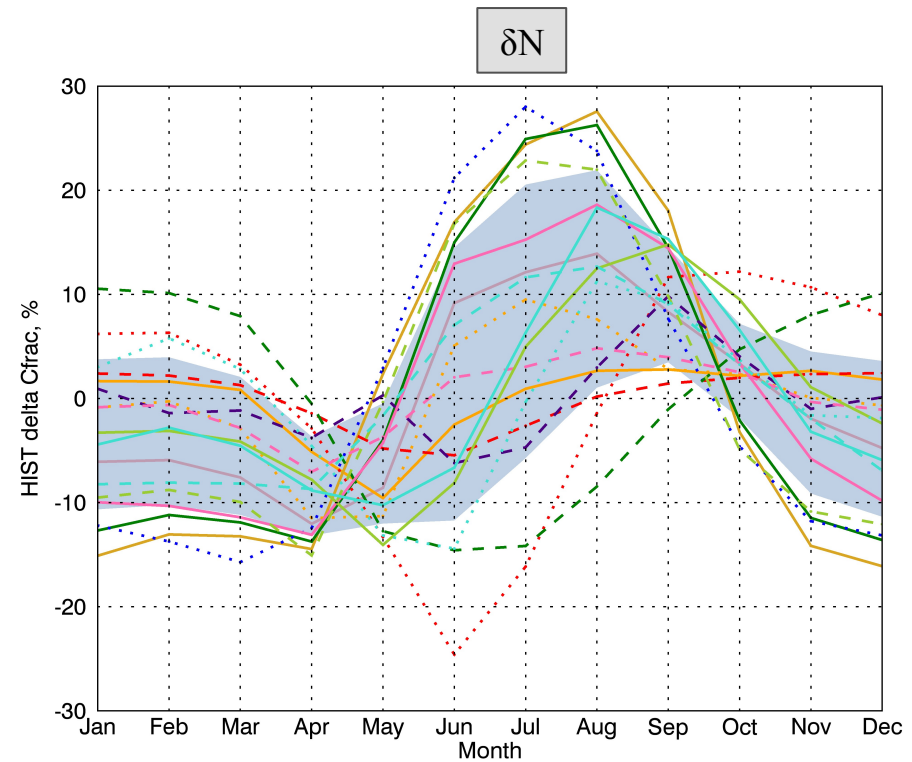
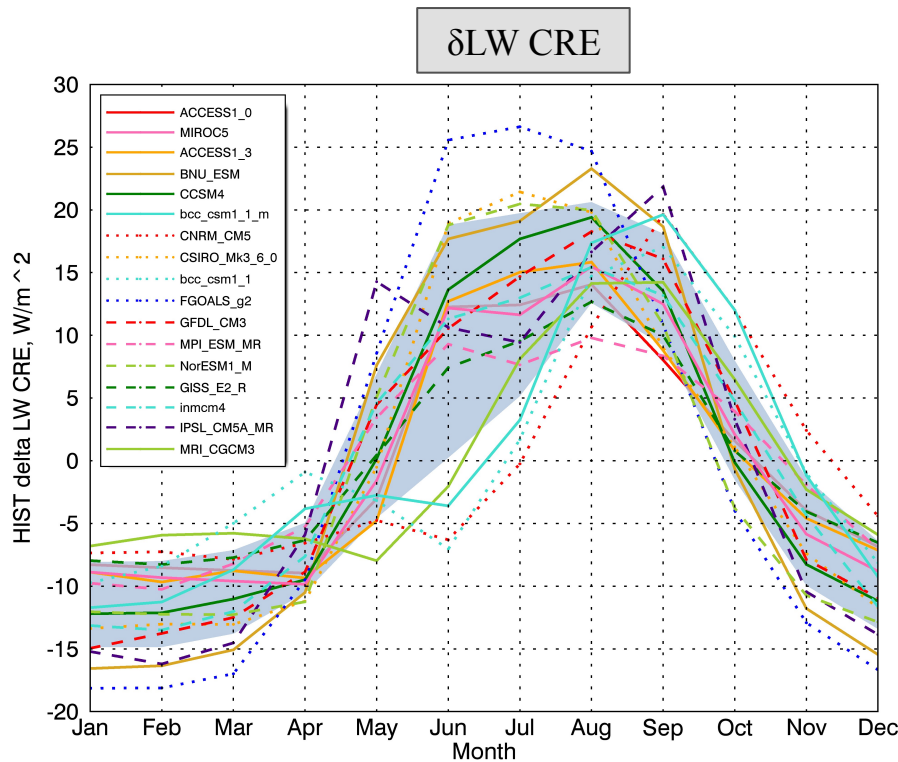
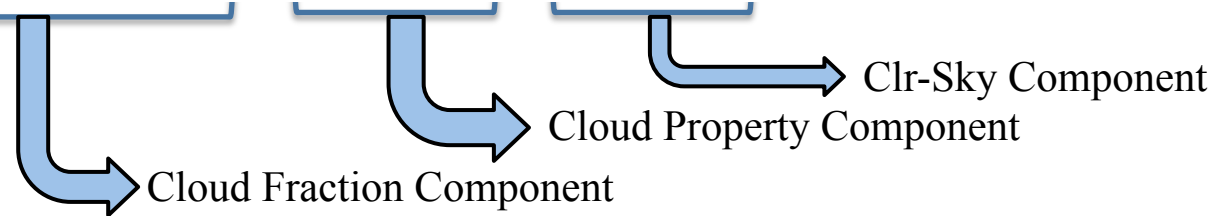


What causes differences in LW CRE?

$$LW\downarrow_{all} = (1 - N) \cdot F\downarrow_{clr,lw} + N \cdot F\downarrow_{cld,lw}$$

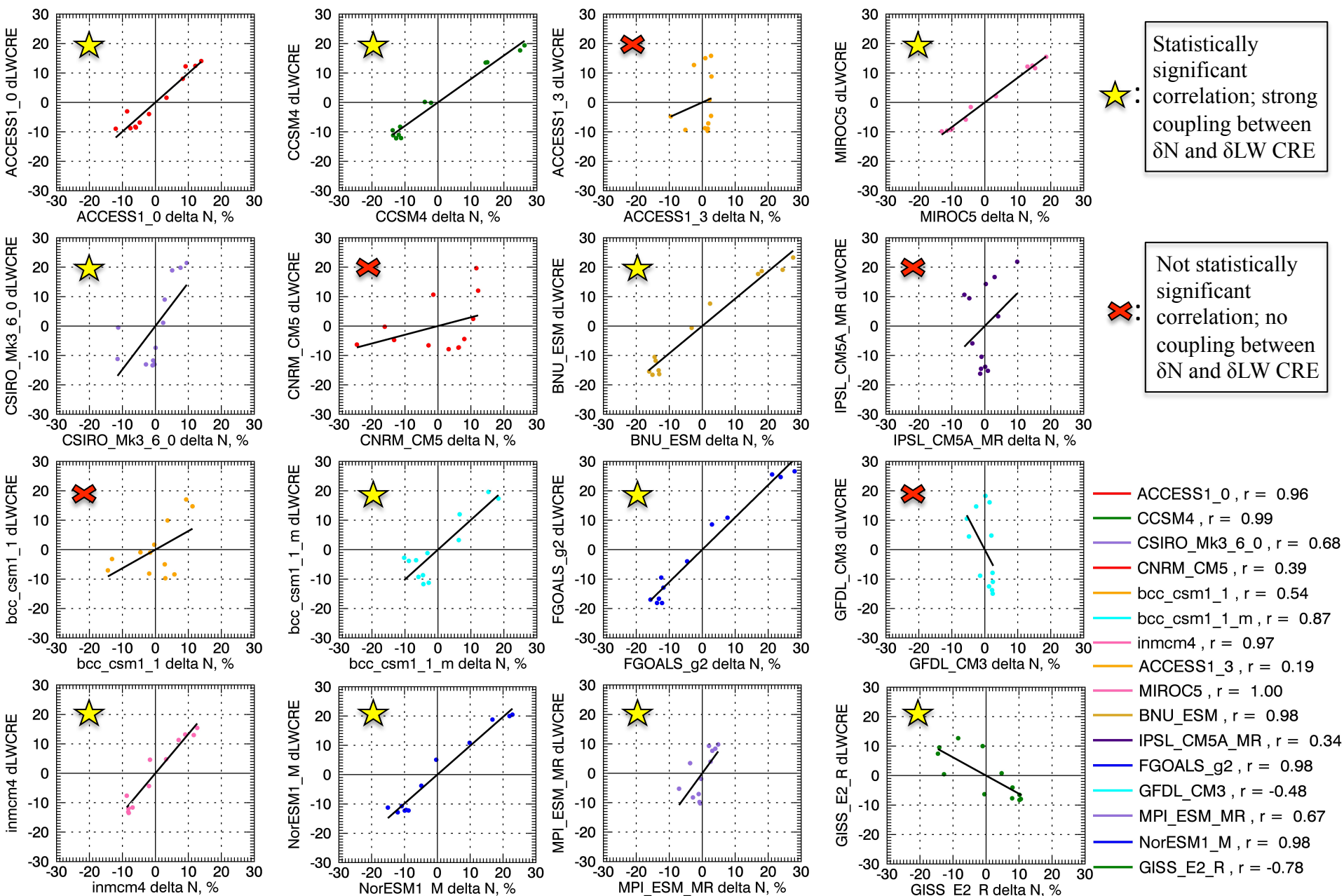
$$LW\ CRE = LW\downarrow_{all} - LW\downarrow_{clr} = N \cdot (F\downarrow_{cld,lw} - F\downarrow_{clr,lw})$$

$$\delta LW\ CRE = \underbrace{\delta N \cdot (F\downarrow_{cld,lw} - F\downarrow_{clr,lw})}_{\text{Cloud Fraction Component}} + \underbrace{N \cdot \delta F\downarrow_{cld,lw}}_{\text{Cloud Property Component}} - \underbrace{N \cdot \delta F\downarrow_{clr,lw}}_{\text{Clr-Sky Component}}$$



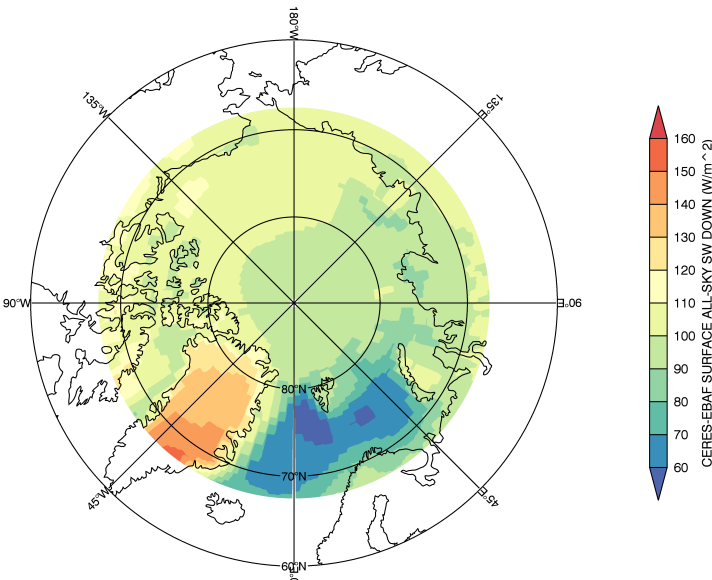
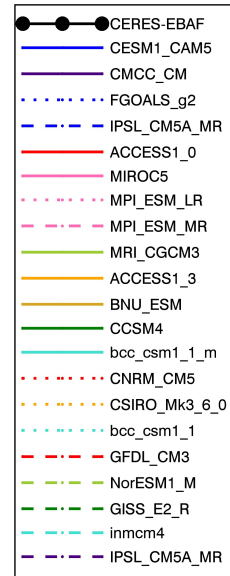
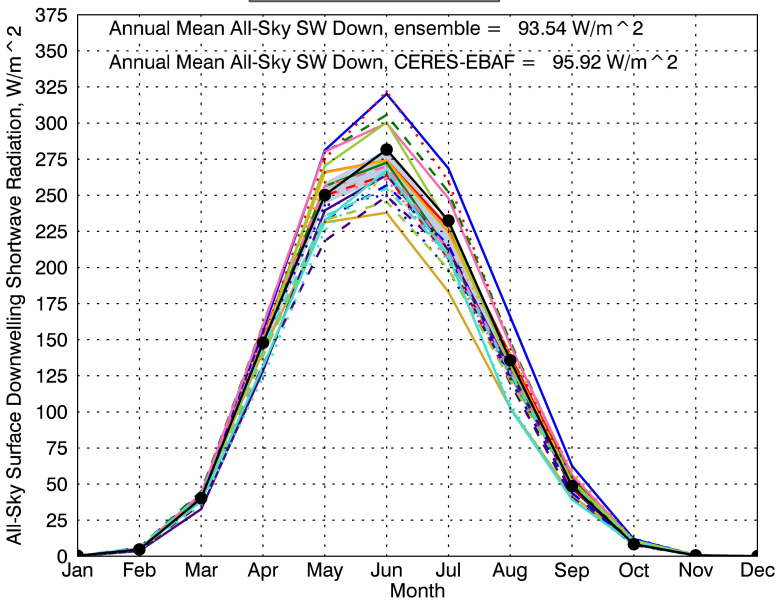
(grey shaded region is the ensemble mean +/- one standard deviation)

For some models, changes in LW CRE are closely coupled to changes in cloud fraction

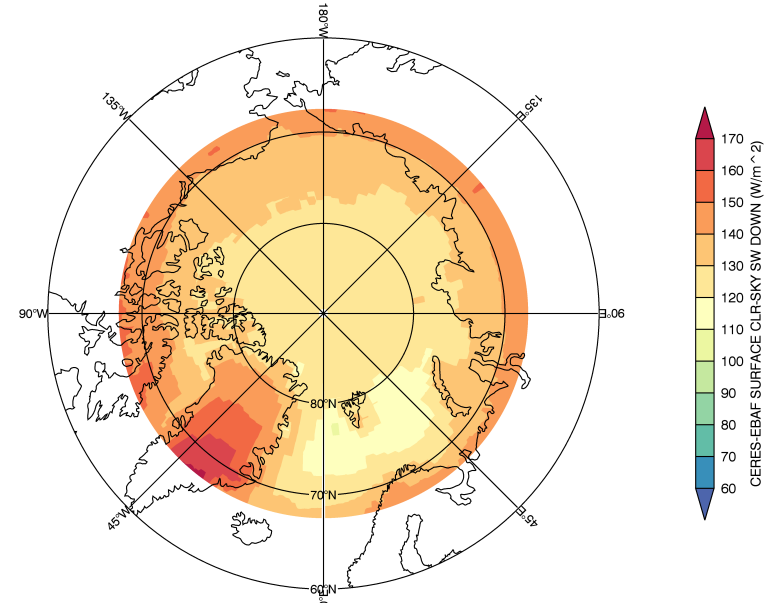
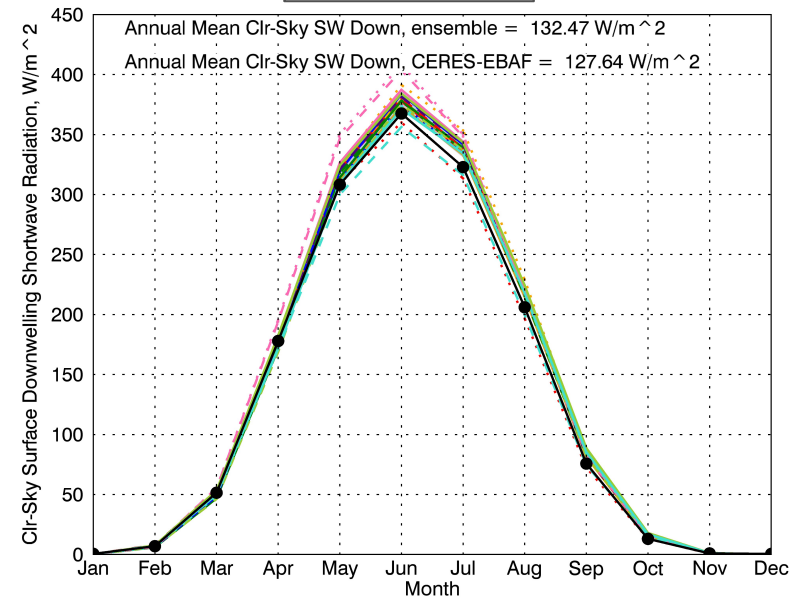


Shortwave Surface Fluxes

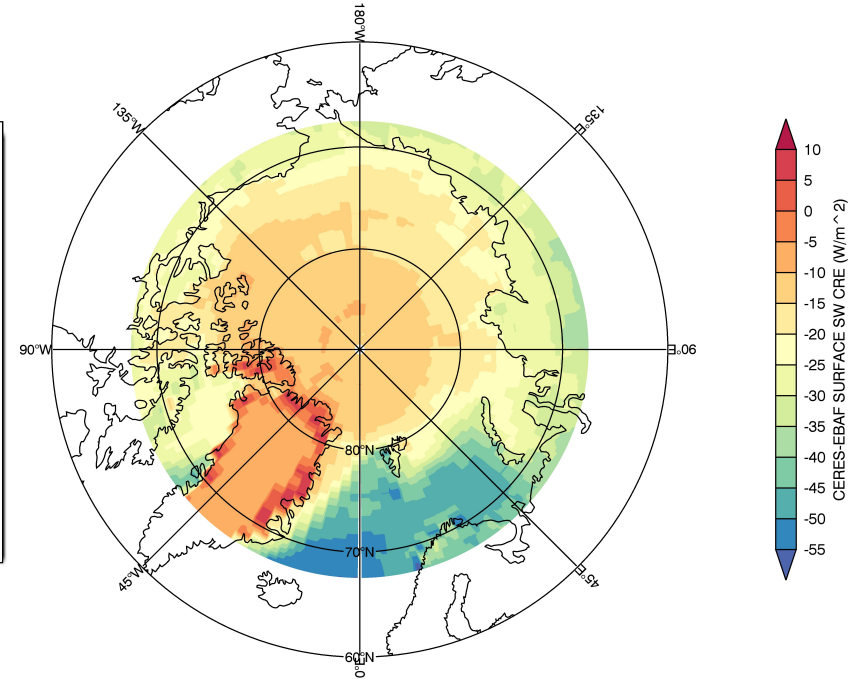
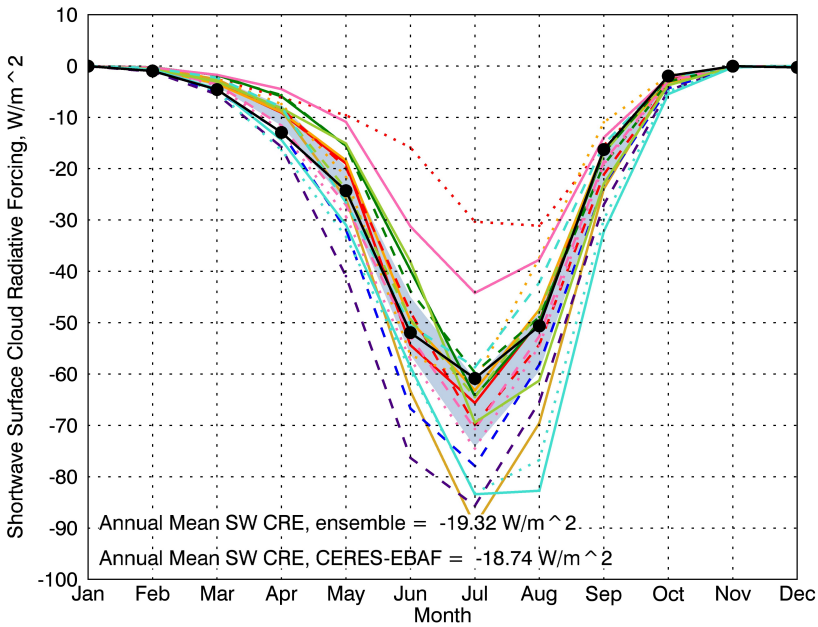
All-Sky



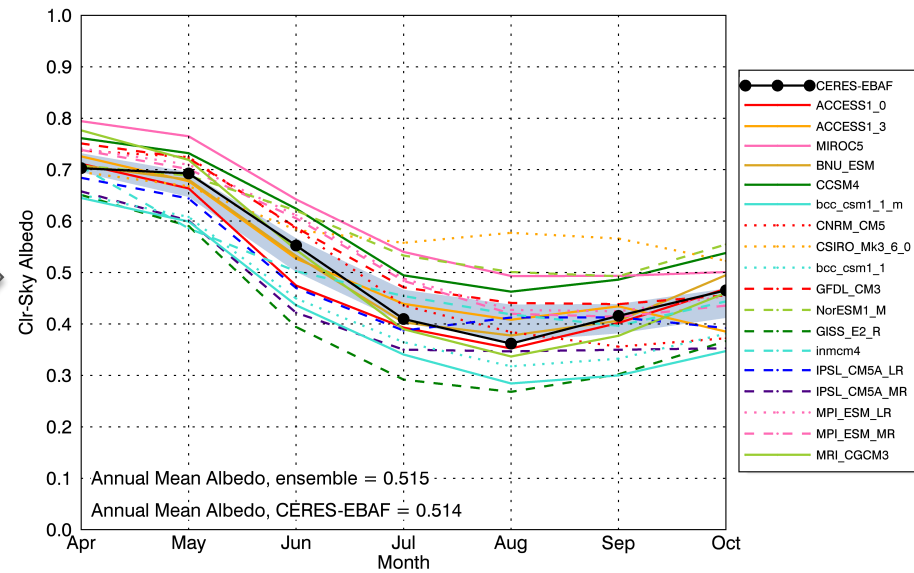
Clr-Sky



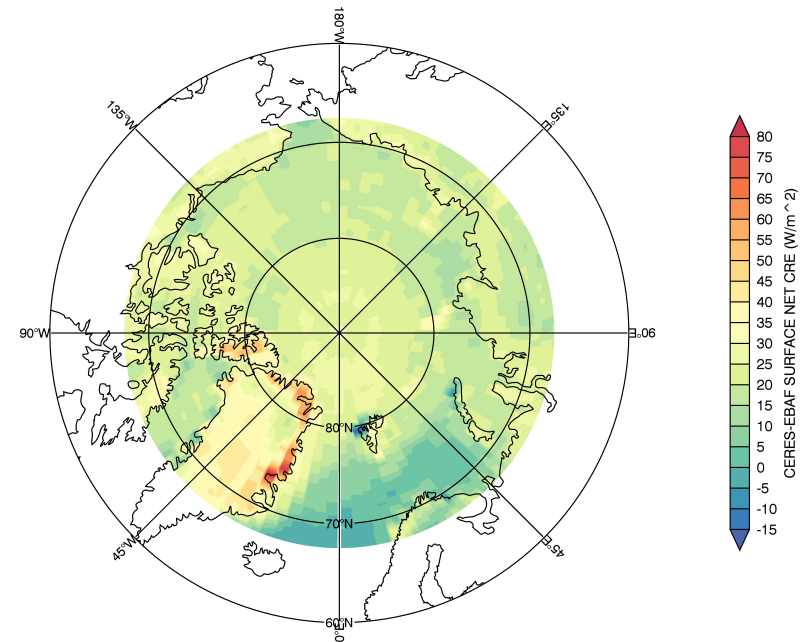
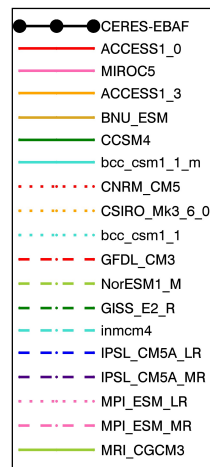
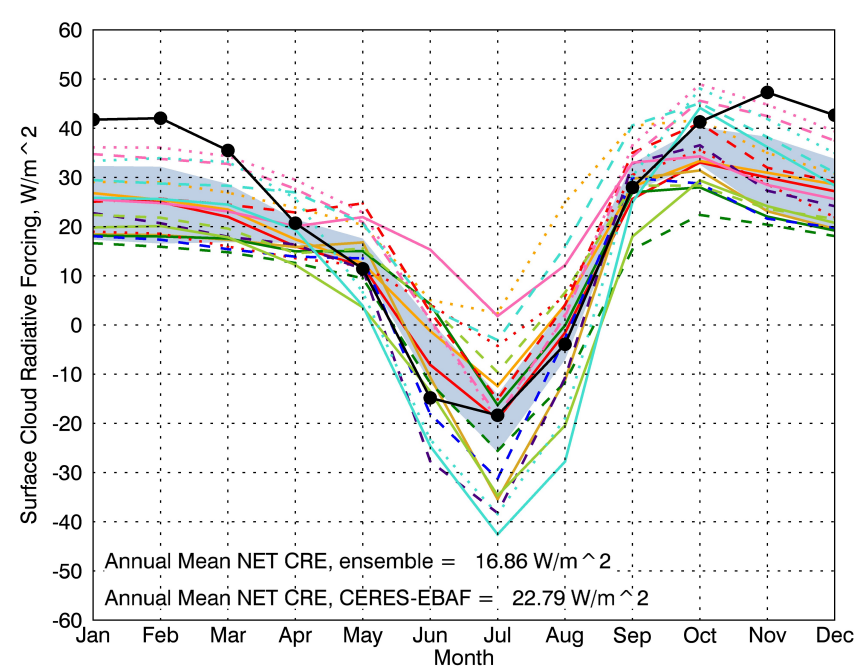
Shortwave Cloud Radiative Effect



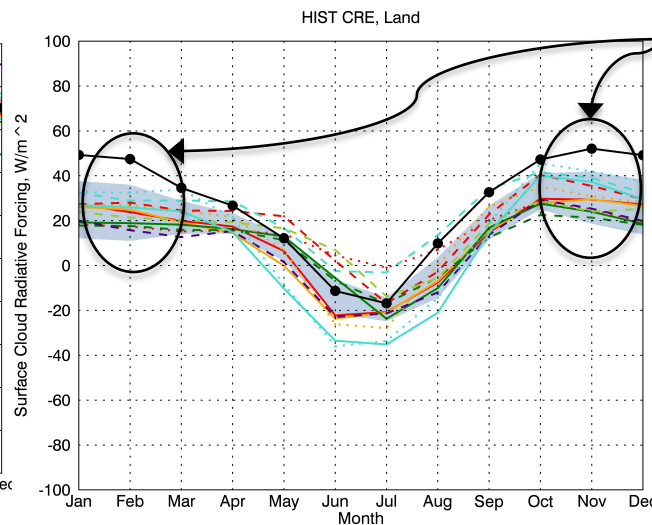
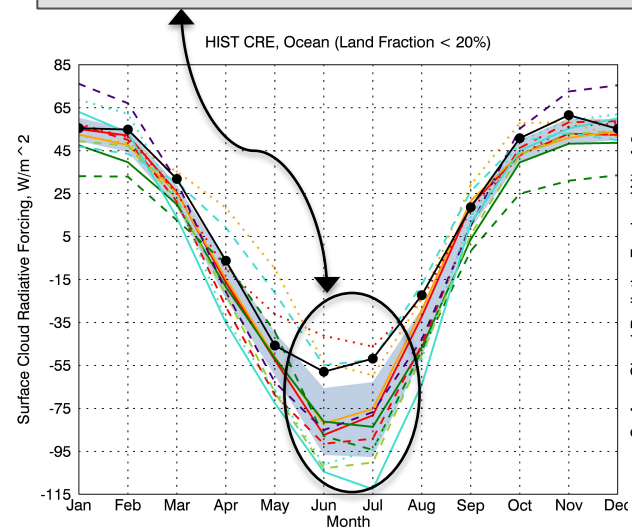
Generally, models with higher surface albedo have a weaker SW CRE and vice versa (Karlsson and Svensson 2013)



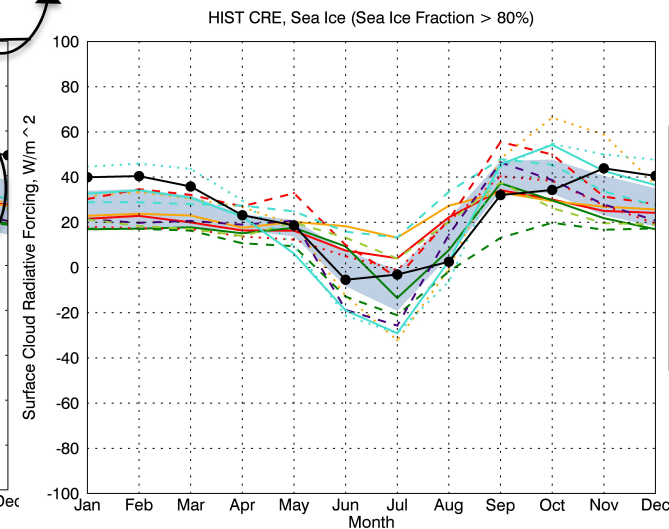
Net Cloud Radiative Effect



Summertime bias in Net CRE occurs over ocean

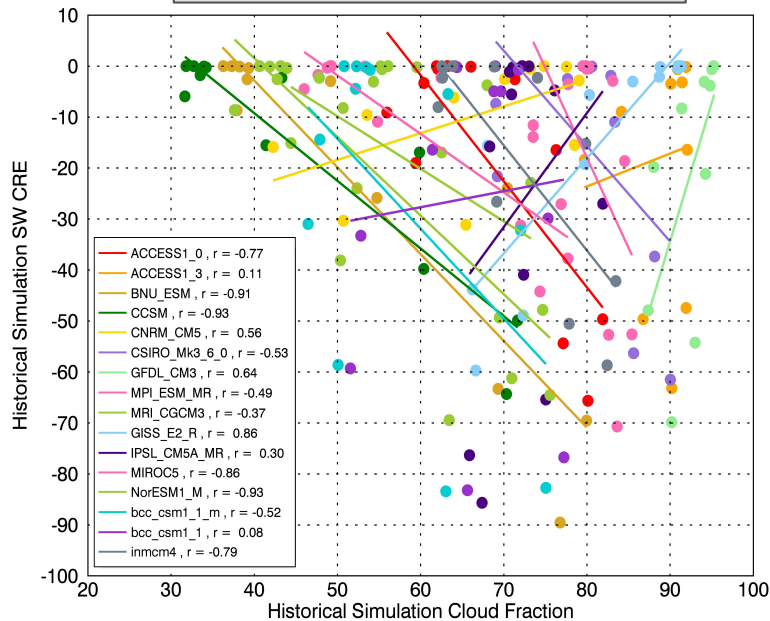


Winter bias in Net CRE occurs over land

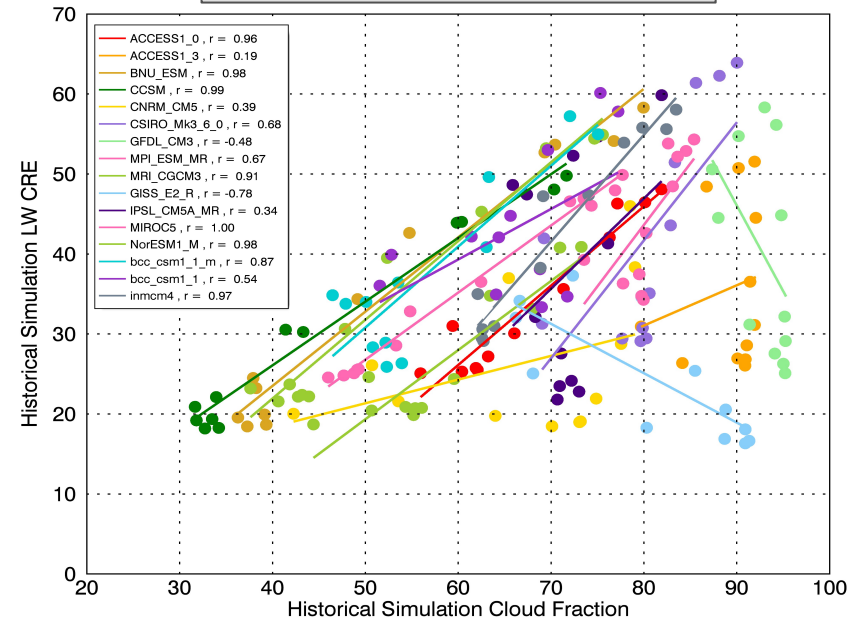


Regressions between cloud fraction and net CRE show whether a model is more strongly forced by a **cloud albedo effect** or a **cloud greenhouse effect**

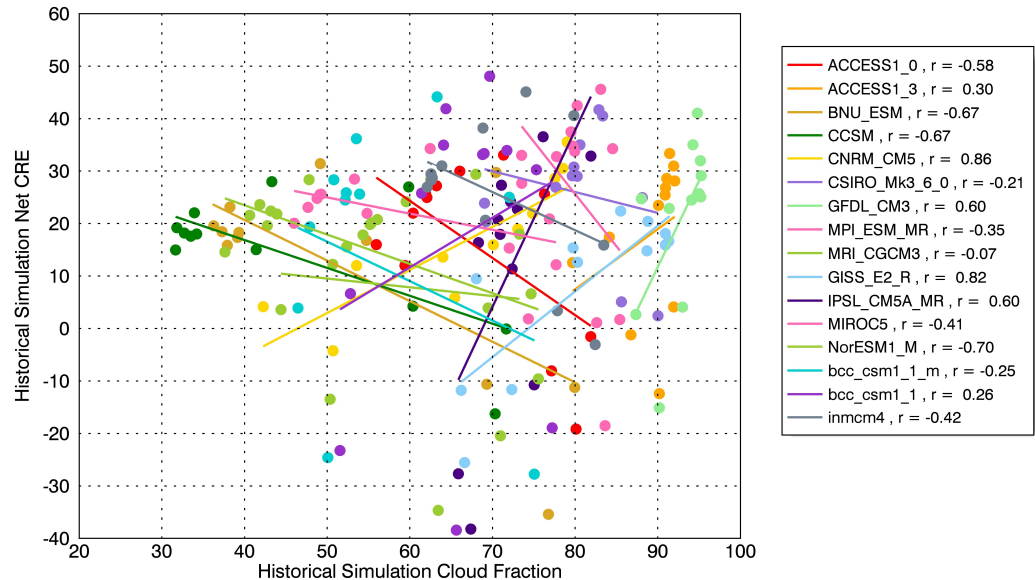
SW CRE vs Cloud Fraction



LW CRE vs Cloud Fraction



Net CRE is the result
of adding the
longwave and
shortwave forcings

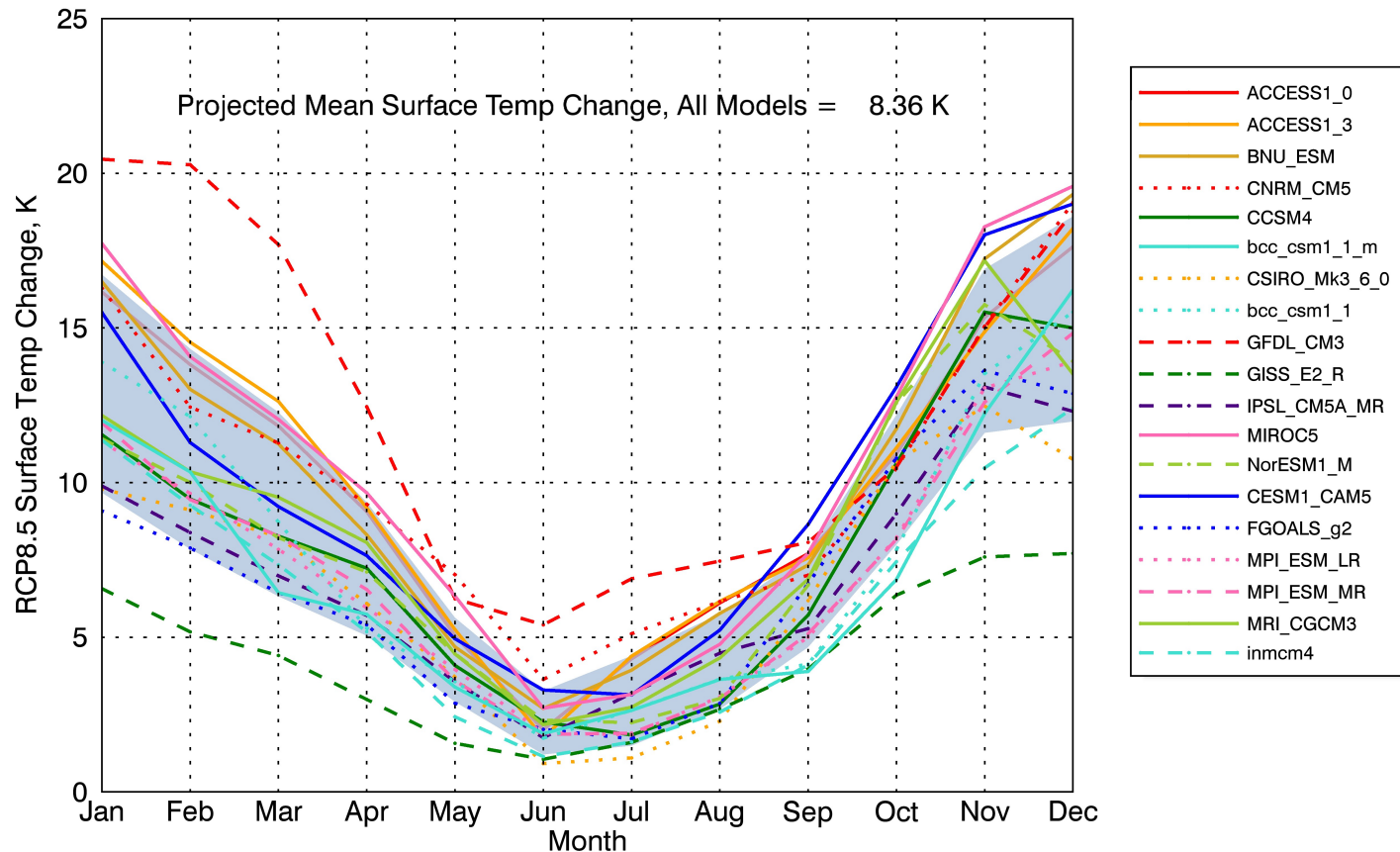


How will Arctic surface temperature change in the future?

Future surface temperature is obtained using the RCP 8.5 simulation (**R**adiative **C**oncentration **P**athway 8.5, a projection dataset with an 8.5 W/m² forcing)

RCP 8.5 runs from 2006 to 2100. Temperature change is calculated as follows:

$$\Delta T_{\text{surf}} = \text{Mean } T_{\text{surf}} \text{ for the last 20 years of the simulation} - \text{Mean } T_{\text{surf}} \text{ for the first 20 years of the simulation}$$

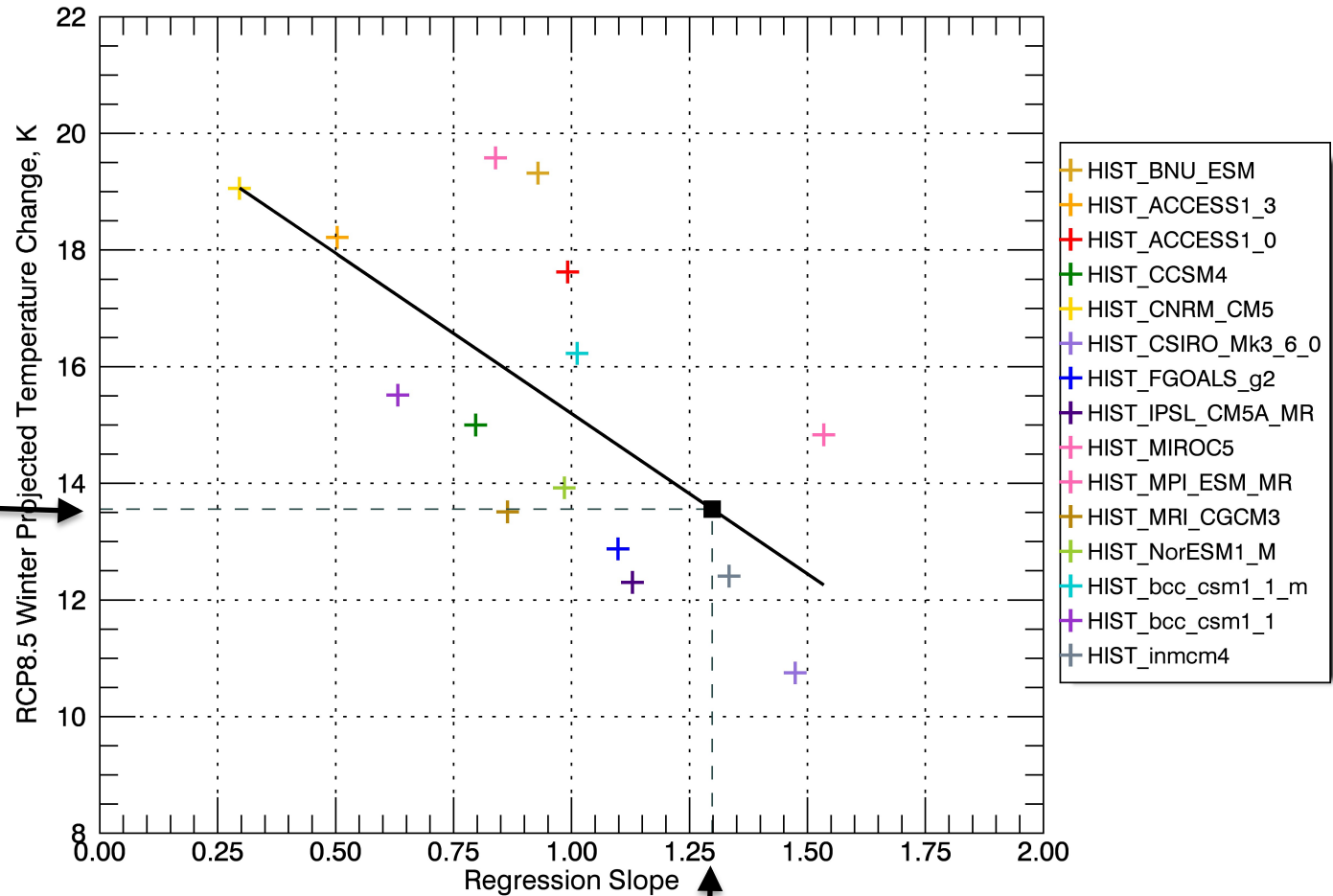


(grey shaded region is the ensemble mean +/- one standard deviation)

The sensitivity of a model to changes in clouds is correlated to projected surface temperature change

The slope of the regression line from the δN vs δLW CRE is compared to projected ΔT_{surf} for CMIP5 models and C3M observations

Using the model line fit and the C3M regression slope, a predicted ΔT_{surf} for observations is ~ 13.6 K



C3M regression slope

Questions?

Contact Information:

Robyn C Boeke

phone: 757.951.1612

robyn.c.boeke@nasa.gov